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Hienert, Daniel

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A Model for the Integration of Interactive Visualizations into the Process of Information Searching and Linking on the Web

Daniel Hienert *

Abstract: »*Ein Modell für die Integration von interaktiven Visualisierungen in den Prozess von Informationssuche und Informationsverlinkung im Web*«. The Web provides access to a mass of heterogeneous information such as: websites, news, articles, statistics, numbers, facts and so on. Accessing this information through search engines and browsing is nowadays a standard procedure for everyone. Interactive visualizations are not yet an integral part of this search process due to a long-time lack of standards for native graphics on the Web and a lack of models for their connectivity. However, interactive visualizations provide a lot of benefits like (1) a variety of different representations for big, heterogeneous and complex information and (2) their interactivity that supports the cognition process of the user. In this article, a model for the integration of interactive visualizations into the process of information searching and linking on the Web is developed. This enables interactive visualizations to be an integral part of the web search process. The model has been used as basis for the implementation of the Vizgr toolkit and has been applied and tested in different application scenarios. This article is a shortened and revised summary of the relevant chapter in the dissertation of Hienert (2013).

Keywords: Interactive visualizations, information visualization, information retrieval, linking of information, World Wide Web, model, theory.

1. Introduction

The amount of information on the Web is constantly increasing (Hilbert and López 2011), and there is also a wide variety of information available such as: news, encyclopedia articles, statistics, survey data, stock information, events, bibliographies etc. The information is characterized by heterogeneity in aspects such as: information type, modality, structure, granularity, quality and by its distributed nature. The two primary techniques by which users on the Web are looking for information are (1) using web search engines and (2) browsing the

* Daniel Hienert, GESIS – Leibniz Institute for the Social Sciences, Unter Sachsenhausen 6-8, 50667 Cologne, Germany; daniel.hienert@gesis.org.

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links between information (Olston and Chi 2003). The dominant mode of information presentation is mainly static in the form of text, images and graphics.

Interactive visualizations offer a number of advantages for the presentation and exploration of heterogeneous information on the Web: (1) They provide different representations for different, very large and complex types of information and (2) large amounts of data can be explored interactively using their attributes and thus can support and expand the cognition process of the user. So far, interactive visualizations are still not an integral part in the search process of the Web. The technical standards for native (interactive) graphics, the connectivity of its information content, but also interaction paradigms to make interactive visualization usable by the mass are only introduced slowly in the World Wide Web.

This article examines how interactive visualizations can be used for the linking and search process of heterogeneous information on the Web. Basis are the fundamentals in the areas of Information Retrieval (IR), Information Visualization (IV) and Information Processing (IP), which are discussed in detail in the following article (Hienert 2014). Based on that, a model is created which extends the existing structural models of Information Visualization with two new processes: (1) linking of information in visualizations and (2) glyph-based searching, browsing and filtering.

The first process utilizes the advantages of visualizations for the linking of heterogeneous information. These can be displayed in different visualizations; the user can filter down to the required information and then link these information objects with a simple interaction metaphor directly within the visualizations. This has the advantage that information can be easily connected directly in the search process and forms the basis for further search techniques such as browsing or brushing-and-linking.

The second process allows the integration of visualizations into a general search process. With the ability to connect any visual element with search techniques, interactive visualizations can be integrated as an intermediate step in an exploratory search. So far, visualizations mostly represent individual data sets without considering the possible connections to other information on the Web. Large amounts of data can now be integrated quickly and easily accessible for the user in the search process, and are thus extending the standard web search.

2. Benefits and Limitations of Interactive Visualizations

Interactive Visualizations offer a number of advantages for the visualization, search and analysis of data and information. Card et al. (1999) define Information Visualization as "*The use of computer-supported, interactive visual representations of abstract data to amplify cognition*". They summarize in which aspects interactive visualizations can enhance the cognition process and propose six aspects how Information Visualization can achieve this: (1) The human memory and processing power can be increased through interactive visualizations, e.g. by offloading work from the cognitive to the perceptual system, (2) the search for information is reduced, (3) the pattern recognition is supported by visual representations, (4) inference processes of perception are possible, (5) attention processes of perception can be used for monitoring and (6) information are transferred into a manipulable medium. North (2005), in particular, points to the effect of gaining insight. Through the ability of the human brain to draw visual conclusions, knowledge or insight can be generated. With this capability, mental models of real phenomena that are represented in the data can be formed. Simple insights for example could derive from observing the maximum in a line graph or finding known items. More complex insights can result for example by the recognition of patterns or relationships in a visualization. Schierl (2001) provides a supplementary list of general advantages of images over text from the perspective of the advertising industry, which are supported by several psychological studies: (1) images have a high communication speed, (2) images are perceived almost automatically, (3) images are always fixed first before the text, (4) pictorial information is processed more efficiently than textual information, (5) images convey subtle emotions, (6) images appear to be particularly objective and credible, (7) images are especially vivid and (8) images support the spatial imagination.

Further advantages arise from the transfer of visualizations to the Web. McKeon (2009) adapts the classical visualization pipeline to the Web, which shows how from raw data an interactive visualization is developed with which the user can interact. The individual process steps such as data holding, data aggregation, visualization and further use can be implemented with different online tools that are interconnected with each other. In particular, Heer et al. (2009) refer to the collaborative aspect of visualizations on the Web with the mantra "Point, Talk, Publish". Data and visualizations can be published in online systems, and those interested can analyze and discuss interesting aspects and patterns in visualizations independent of time and location. Similar to the collaborative analysis of data and visualizations offline, online participants should be able to make references to specific aspects in visualizations ("Point"), to talk about these aspects ("Talk") and to publish various views of a visualization ("Publish").

The predominant paradigm for visual exploration of data in visualizations is the information-seeking mantra of Shneiderman (1996): "*Overview first, zoom and filter, then details-on-demand*". This means, starting from an overview, the user navigates and filters down to data points of interest. Here, the user can retrieve detailed information for the data point or can browse to related elements in the data set and in the visualization. The information-seeking mantra is also used for the display and faceted filtering of information on the Web.

Therefore, popular web visualizations such as tag clouds, maps, charts, but also other types are used. For example, Wood et al. (2007) use tag clouds and tag maps for the interactive display of log data of a mobile application for local information in Google Earth. Tags can be used for filtering this data. The system VisGets (Dörk et al. 2008) combines various visualizations such as a map, a tag cloud and a column chart for representing and filtering of retrieved web resources such as RSS feeds, Wikipedia entities or Flickr photos based on facets such as time, place and subject. Based on the concept of dynamic queries results can be interactively filtered through the manipulation of the visualizations. A similar approach is used by a system for the dynamic display of Twitter messages that are posted to a particular event or topic (Dörk et al. 2010). In three different visualizations, metadata facets of the messages are displayed, which can also be used for filtering the messages and which are interconnected by the brushing-and-linking technique.

This way, visualizations offer a lot of benefits for the display, analysis and processing of data and information and support the user in the analyzing task. The transfer of visualizations to the Web now also allows the analysis of web information. Thereby, the analysis process online is still focused on the Shneiderman mantra. However, information in online visualizations can contain implicit and explicit links to other related information on the Web. A model for the search, learning and investigation steps in web search is the Exploratory Search Model by Marchionini (2006). Here, it is pointed out that different types of cognitive processes such as "scanning/viewing, comparing and making qualitative judgments" are required to process the information. The question that arises is how interactive visualizations can support these cognitive processes. Visualizations should not only support to analyze one information space, but also should help to compare and connect different information. Based thereon, interaction and search techniques from the field of Information Retrieval such as browsing, searching, filtering can help to support these processes. In the next section a theoretical model is developed that meet these requirements.

3. Building a Model for Integration

In this section, a model is developed that arranges information, visualizations and interactions techniques on different levels and integrates them into an overall search process. It is based on structural models of Information Visualization as well as on fundamentals of Information Retrieval and Information Visualization such as the heterogeneity of information on the Web, their mapping to coordinated views, and different interaction techniques. The focus lies on new processes such as linking of information in visualizations and the integration of visualizations in the search process.

Existing models for structuring Information Visualization (Shneiderman 1996; Card, Mackinlay and Shneiderman 1999; Keim 2002; North 2005) distinguish roughly between (1) information structures, (2) visualization techniques, and (3) interaction techniques. These categories are used in the following as abstract layers for building the model. Thereby, we focus on heterogeneous information on the Web as a starting point and the supplement of the model for (1) the linking of heterogeneous information in visualizations and (2) the integration of visualizations into an overall search process.

3.1 The Information Layer

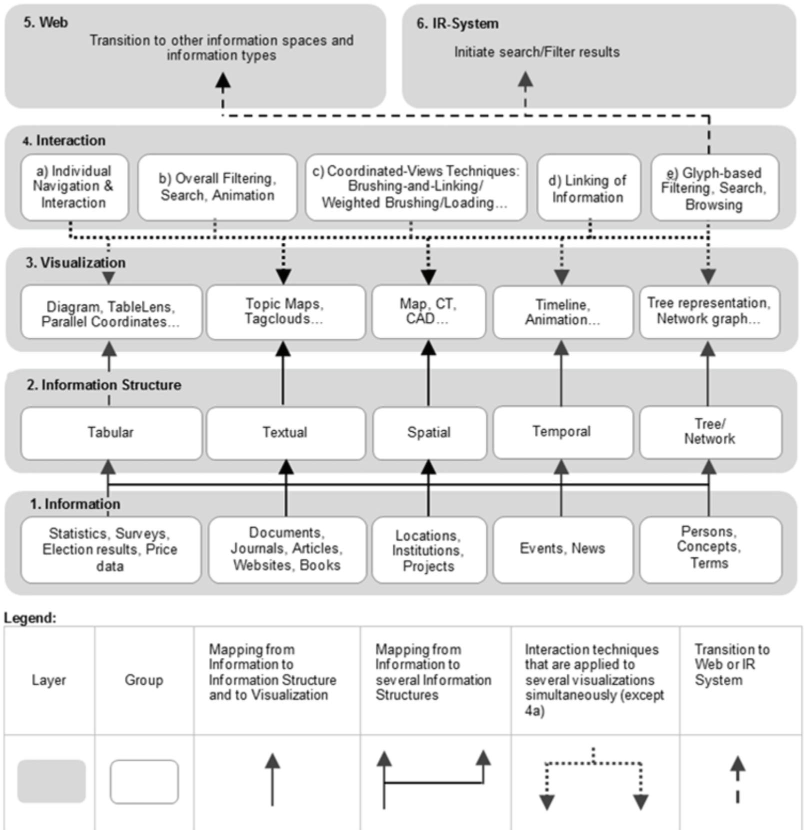
In addition to the basic classification of information in different types of data (such as text, numbers, images, maps etc.), information on the Web has more complex features (Lewandowski 2005; Mandl 2006), e.g.:

- It comes from distributed databases: websites, web encyclopedias (e.g. Wikipedia), web databases, web APIs, web archives, etc.
- It has various modalities: text, image, video, sound, but also a variety of media formats such as HMTL pages, Office documents, PDF, JPG, GIF, WAV, MP3, FLASH, DIVX etc.
- It has different structures: Web pages are indexed by their text content, audio and video documents are annotated by keywords. Content in web databases (e.g. news articles) are annotated with several metadata attributes.
- It can show different granularities: The granularity can range from raw data to complex information types or objects.
- It can show different qualities: The quality of the resource can vary in several attributes.

On the Web, this heterogeneous information is (1) indexed by its content and attributes and is available in web search engines, and (2) is linked with each other and can be followed by browsing.

Figure 1 shows on the first level examples of heterogeneous information types as it can be found on the Web. The information types are already arranged in groups, which primarily have a tabular, textual, spatial, temporal or tree-/network information structure.

Figure 1: A Model for the Integration of Interactive Visualizations in Information Searching and Linking on the Web



3.2 The Information Structure Layer

In the sense of Information Visualization, these complex types of information can be mapped to basic information structures. North (2005) notes:

> but more advanced methods are needed as data complexity increases. Identifying underlying structures within the target information helps to further guide the design process (North 2005, 1226).

Figure 1 shows how information can be mapped to information structures. Layer 1 depicts the level of heterogeneous information as it can be found on the Web. Layer 2 is the level of information structures, consisting of tabular, textual, spatial, temporal or tree-/network structures. Each information type from level 1 can be mapped to one or more information structures of level 2. For example, statistics primarily have a tabular information structure, websites primarily have a textual information structure and events have a temporal information structure. This is indicated by the arrows that point directly upwards from information (layer 1) to information structures (layer 2).

More complex information can consist of multiple information structures. This is shown in Figure 1 by the possibility to follow the arrow from one information object to multiple information structures. For example, statistics can consist simultaneously of tabular, spatial and temporal information structures. The data set may be a table with combinations of country, year and indicator value. The entire data set is therefore structured in tabular form, the distribution of countries can be mapped to a spatial information structure, the distribution of years to a temporal information structure. These information structures will be used in the next step for the initial visualization of the information.

3.3 The Visualization Layer

For the visualization of information, information structures are used as an aid for the initial visualization. North writes:

> These structures provide guidance for the design of appropriate visualizations. Since these structures are likely to be very important to users' mental models of the information (North 2005, 1226).

One can distinguish between (1) a single view for displaying an information structure of one information and (2a) multiple views for the display of different information structures of one information and (2b) multiple views for the display of one information structure of several related information.

Coordinated Multiple Views (CMV) (cp. Wang Baldonado, Woodruff and Kuchinsky 2000; North and Shneiderman 2000) are the standard procedure for displaying combined information structures in Information Visualization. These individual information structures or attributes are visualized with a matching visualization type in separate views simultaneously. The linking between information and information attributes can be used to visually link the different views with each other. A much-used technique for this is brushing-and-linking, where data can be selected in one view and related data will be highlighted in all other views.

So far, the focus for CMV in IV lies on the process (2a). Different information structures of an information object are visualized in different views in order to examine the different aspects. Here, a connection already exists between the different information structures by the information object itself and does not need to be created. For example, the different structures of statistical data such as tabular, spatial and temporal structures can be visualized in multiple views with a list, a map and a diagram. The process (2b) offers a new possibility to use multiple views for the visualization of heterogeneous information with a relationship. Here, not only one piece of information is visualized, but several ones. The simultaneous display in several views allows new processes such as the linking of information within visualizations.

On the third level, the visualization layer in Figure 1 is presented. It contains examples for initial visualizations such as diagrams, tag clouds, maps, timelines or network graphs (direct arrows from information structures to visualization examples).

3.4 The Interaction Layer

On the level of interaction can be distinguished between (a) overview, navigation and interaction techniques which are optimized for a single view and (b) techniques that are applicable to multiple views, and (c) coordinated-views techniques that are based on the connection of multiple views. Based on that, techniques (d) for the linking of information in visualizations and (e) for glyph-based filtering, searching and browsing are added. On the fourth layer the interaction layer with all processes is shown in Figure 1. Dotted arrows indicate interaction processes that can be applied to multiple visualizations simultaneously (except interaction process 4a).

3.4.1 Individual Navigation & Interaction Techniques

The individual visualization provides different interaction and navigation techniques depending on the visualization type, the represented information and data set and the application scenario. (Shneiderman 1996; Card, Mackinlay and Shneiderman 1999; Keim 2002; North 2005) give an overview of possible interaction techniques in visualizations. Common examples are the zoom & pan options in maps or the selection of some nodes in a network graph (dotted arrow from process (4a) to the individual visualization).

3.4.2 Overall Filtering, Search & Animation

Multiple views can be filtered, searched, or animated at the same time with an additional user interface component. The module contains widgets for filtering attributes and values, for the search of values and for the animation of all visualizations. Interaction elements are: selection lists, dynamic sliders, a search box and the possibility to start animations and to choose points in time explicitly. In this way, multiple visualizations can be filtered, searched, or animated simultaneously although the user performs only one interaction step. This is shown by dotted arrows from process (4b) to all the visualizations in Figure 1.

3.4.3 Coordinated-Views Techniques

Coordinated-Views techniques are used to connect various views with an interactive linking. For example, related attributes are linked in different views with the brushing-and-linking technique (Becker and Cleveland 1987). The selection of items in one view results in the highlighting of related items in all other views. Based on this, weighted-brushing (Dörk et al. 2008) highlights related items according to their number of associations with different color shades. Another action may be "loading", where selecting or clicking items in one view, loads content in other views. In general, every action can be coordinated to different views, which is formalized in the Snap-Visualization-Model (North et al. 2002). Dotted arrows from process (4c) to all the visualization types in Figure 1 show that coordinated-views techniques are applied to several views at the same time.

3.4.4 Linking of Information in Visualizations

Connections and links between information can exist at different levels: (1) one piece of information can consist of several attributes which are connected by the information itself, (2) connections can exist between information objects such as joins, queries, linkings, or predicates, and (3) information resources on the Web can be a linked, or information is semantically annotated and linked, e.g. with Microformats/RDFa or in the Linked Data Cloud.

If no technical or formal connection exists between different (heterogeneous) information, but there is already a cognitive relationship by the user, visualizations can be used to directly create this linking. Thereby, advantages of visualization in general (such as interactivity and "amplifying cognition" (Card, Mackinlay and Shneiderman 1999)) and advantages of various visualization types to optimally represent the information and to make it explorable are utilized. For example, large amounts of statistical data can be better navigated in a diagram where significant points and trends can be detected intuitively. In addition, different information can be best represented in different visualization types. For each information type, an optimized representation is given including navigation and interaction possibility. Figure 1 shows that the linking process can be applied to various visualizations and thus also to the underlying information (dotted arrow from process (4d) to all visualizations, then to information structures and then to the underlying information).

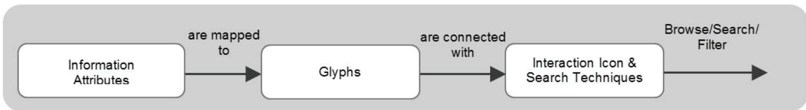
In the first step, two datasets are visualized in two optimal visualizations. In the next step, these two visualizations are shown on the user interface side by side. Users can use common interaction techniques such as filtering, zooming and panning to navigate to the information of interest. Then, one or more elements in each of the visualization can be selected with the mouse, and are thus already connected. The connection can be visualized with a line between the two glyphs. Further, the connection can then be annotated with arbitrary attributes, for example, with a predicate in the sense of the Semantic Web or with a confidence value for the strength of the association.

3.4.5 Glyph-Based Filtering, Search & Browsing

Several systems already use glyphs (visual elements like bars in a bar chart) in visualizations to filter or search for information. Popular examples are tag clouds used in web information systems to filter documents, news, messages or bookmarks by a keyword. Also on the Web, this approach is used to filter web information with coordinated views such as tag clouds, time diagrams and small maps (Dörk et al. 2008).

The concept can be abstracted by connecting glyphs of different visualization types with an interaction icon which can trigger various actions such as browsing, searching or filtering processes. Figure 2 shows the abstract view: information attributes are mapped to glyphs of visualizations. They can be connected on the data level with an interaction icon and an interaction technique. A click on the icon then triggers a browsing, searching or filtering process.

Figure 2: Mapping of Information Attributes to Glyphs, which can be Connected with the Interaction Icon. A Click can Trigger Browse, Search or Filtering Actions



3.5 Integration of Visualizations into the Search Process

Based on a linking between information (see 3.4.4) and different glyph-based search techniques (3.4.5), visualization can now be used as an intermediate step in the search process of IR-Systems or an exploratory search on the Web. So far, interactive visualizations on the Web were isolated, because there is no connection to related information outside. With the introduction of new interaction techniques such as browsing, visualizations can now be integrated into an iterative search process. Figure 1 shows how visualizations can be connected based on glyph-based filtering, searching and browsing with the Web or an IR system (dashed arrow of interaction process (4e) to level 5 (Web) and level 6 (IR system)).

4. Application of the Model

The Vizgr toolkit <www.vizgr.org> implements the developed model in a web application. Users can create different visualizations such as charts, tag clouds, maps, timelines and network graphs based on various information structures. The visualizations created can then be displayed in the Mapping Editor and users can manually connect glyphs to web resources or to other visualizations.

The Vizgr application can also be integrated into an IR system or other web applications and glyphs can be connected automatically to browsing, filter or search actions.

In four different application scenarios, aspects of the model have been instantiated and were evaluated in user tests or examined by different scenarios (cp. Hienert 2013). In the first application scenario, it has been evaluated if users are able to create visualizations with the Vizgr toolkit and to link heterogeneous information within these visualizations (proof of concept). About 94% of the users were able to create visualizations, more than 87% of the users were able to link information, and the majority of the users was able to solve the tasks in less than 5 minutes by judging the level of difficulty to solve the task with very easy to normal and was moreover able to explain the general effect.

In the second application scenario, statistical data was combined with related information such as user visualizations or historical events. This heterogeneous information could be integrated at various levels and was made available for the information search process. Based on manually or automatically created links, information could be highlighted and loaded in different views and, thus, made accessible to the user.

In the third scenario, interactive visualizations were integrated directly into the search process of an Information Retrieval system. The user study showed that users could find value-added information and links between information quickly (under a minute) and that the process was assigned an easy to normal difficulty level. A search with the help of glyphs could be performed quickly, easily, and intuitively.

In the fourth application scenario, the Vizgr toolkit is integrated into the exploratory search process in a scenario of stock market information. Here, the newly introduced processes Linking of information in visualizations and Searching, browsing and filtering based on glyphs are combined to link and search heterogeneous information such as price data, financial news and web articles. In a user test, it is shown that users can combine and use these information sources to find related information in an exploratory search process.

As a result of these user tests, it has been shown that (1) interactive visualization can be used for the linking of information and that this process works in principle, being perceived as quick and easy. (2) Glyphs in visualizations can be used for search techniques such as search, filtering and browsing and allow the integration of interactive visualizations in an exploratory search process or the search in an IR system.

5. Conclusion

In this article, a model was developed that first maps heterogeneous information from the Web to information structures in the sense of Information

Visualization. Information structures can then be mapped to initial visualization types that can be combined in coordinated views and are able to represent complex information types and whole information spaces. With the use of coordinated views also various new interaction techniques are made possible. They range from the linking of information in different views to search and filter in IR systems and to the possibility to browse from information in graphics to related information on the Web.

This has some consequences for the role of interactive visualizations on the Web. They are no longer limited to show only simple information attributes such as locations on a map, but they can represent very complex information and information spaces. Interactive visualizations can also support the exploratory search process. This can be implemented in particular through the integration of links directly into visualizations. The web search process will be extended to allow navigation steps between information in visualizations and related information on the Web such as: web sites, articles, encyclopedia articles, news, images, or other graphics. This combines the benefits of Information Visualization and Exploratory Search. First, arbitrary large or small-scale information is presented in user-friendly visualizations with which the user can interact. Second, this information is integrated in the web search process by linking. The user can discover information in visualizations, can browse to related content on the Web, can compare this information, can discover connections, gather background information and can link this information.

In this article, only a short overview of foundations, scenarios and examples could be given, for further details compare (Hienert 2013). The following article gives a deeper insight into the fundamentals of Information Retrieval, Information Visualization and Information Processing.

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